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[Ian Staley](#) *

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Article

Pruned Histories and the Computational Multiverse: What Does Quantum Speedup Ontologically Require?

Ian Staley

Independent Researcher, USA; ian.t.staley@gmail.com

Abstract

Deutsch's influential argument holds that the exponential speedup of quantum algorithms such as Shor's is best explained by computation distributed across ontologically real parallel branches of the wavefunction. This paper interrogates that claim by asking what minimal ontological commitments are actually required to underwrite observed quantum computational advantages. Drawing on the framework of final-state constraints and informational pruning developed in prior work, we argue that Deutsch's computational argument depends on an unpruned Everettian ontology in which all branches persist as computational substrates. We show that pruned-histories interpretations—in which boundary conditions or decoherence-based selection mechanisms restrict the space of ontologically realized branches—can preserve the empirical predictions of quantum computation while denying the parallel-universes inference. The argument requires three positive commitments: a records-based criterion for ontological commitment, a thermodynamically graded boundary between unitary computation and outcome-stabilization, and a positive account of computational speedup grounded in global Hilbert-space structure and entanglement rather than in a population of parallel worlds. We situate this result within the ontological models framework and recent observer-dependence theorems—including Frauchiger-Renner, Bong et al., and Wallegghem et al.—and engage directly with Hewitt-Horsman's functionalist defense of computational branch realism. We conclude that the Deutsch argument, while rhetorically powerful, is interpretation-laden rather than interpretation-neutral.

Keywords: quantum computation; quantum foundations; Many-Worlds Interpretation; final-state constraints; records-based realism

JEL Classification: B41; C60; C65

1. Introduction

The success of quantum computing has reshaped not only computer science but also debates in the philosophy of physics. Among the most rhetorically powerful claims to emerge from this success is David Deutsch's argument that quantum computational speedup demands ontological commitment to the Many-Worlds Interpretation (MWI) of quantum mechanics [1–3]. The argument runs roughly as follows: when Shor's algorithm [4] factors a sufficiently large composite integer, the number of elementary computational steps required by any classical algorithm exceeds plausible resource bounds of the observable universe. The quantum algorithm nonetheless produces the answer. Where, Deutsch asks, does this computation occur if not in parallel branches of the wavefunction? The branches must be ontologically real, and each must constitute a site of computation, for the empirical advantage to make sense.

This paper challenges that inference. We do not argue that MWI is false; we argue that the Deutsch computational argument fails to establish MWI on grounds available to other interpretations. The target is therefore not Everettian quantum mechanics as such, but the stronger

claim that quantum computational speedup independently compels Everettian branch realism. In particular, we develop a pruned-histories alternative in which not all formally allowed branches of the wavefunction are ontologically realized, and we show that this alternative is fully compatible with observed quantum computational speedup. The thesis is therefore modest in form but consequential in implication: empirical quantum computing does not, by itself, vindicate the parallel-computation reading of quantum mechanics.

The position we develop is closer in spirit to Duwell's observation [5] that MWI's explanatory work in quantum computation is done by the ontological status of the universal state vector rather than by the particular ontology of branches, and to Cuffaro's [6–8] sustained argument that the Deutsch computational explanation is one how-possibly explanation among several. We extend these lines by anchoring the alternative ontology in a records-based criterion: ontic status accrues only to outcomes stabilized by environmental coupling, while branches during unitary computation are formally indispensable but not ontologically populated worlds.

Three considerations motivate this investigation. First, the Deutsch argument continues to circulate in popular and semi-technical literature as if it were a knockdown case for MWI, when in fact it carries substantive interpretive freight that is rarely made explicit. Second, recent foundational results—the Frauchiger-Renner thought experiment [9], the no-go theorem of Bong et al. for observer-independent facts [10], and the contextuality-based extensions of Wallegghem et al. [11,12] and Wiseman et al. [13]—have constrained the space of viable interpretations in ways that affect how the Deutsch argument should be read. Third, the framework of final-state constraints and informational pruning developed in prior work [14], with antecedents in two-state-vector formulations [15,16] and recent applications to cosmology [17] and black-hole physics [18,19], provides resources for articulating a no-collapse, single-world-compatible ontology that has not been systematically applied to the question of computational ontology.

The paper proceeds as follows. Section 2 reconstructs Deutsch's computational argument and distinguishes its formal commitments from its rhetorical force. Section 3 surveys the major interpretive alternatives, summarized in Table 1, and establishes that all reproduce the empirical predictions of quantum computation. Section 4 introduces the pruned-histories framework with its formal apparatus. Section 5 contains the paper's central argument: that pruned histories can underwrite quantum computational speedup without committing to a computational multiverse, when supplemented with a records-based criterion (Table 2) and a positive account of speedup as grounded in Hilbert-space and entanglement structure. Section 6 formalizes the analysis within the ontological models framework. Section 7 discusses implications of recent observer-dependence theorems, including Steane's [20] argument that extended Wigner's friend results do not discriminate single-world from many-world ontologies. Section 8 offers a cautious positive account of what empirical quantum computing actually demonstrates. Section 9 concludes.

2. The Deutsch Computational Argument

Deutsch's argument has been articulated in multiple forms across his published work [1–3,21], with the clearest popular statement appearing in *The Fabric of Reality* [2] and the most technical statement in his analysis of multiverse structure [21]. The structure of the argument can be reconstructed as follows.

Premise (i): Shor's algorithm [4] factors an n -bit integer in time polynomial in n , whereas the best known classical algorithms require superpolynomial time, although no unconditional proof of classical hardness is known. For sufficiently large n , the classical computational requirements exceed any plausible resource budget available within the observable universe.

Premise (ii): The quantum algorithm reliably produces the correct factorization on physical quantum hardware, as has been demonstrated in principle for small inputs and is not in dispute as a matter of formalism.

Premise (iii): Computation requires a physical substrate. If a computation is performed, there must be physical resources that perform it.

Conclusion: The computational work performed by Shor's algorithm exceeds available classical resources in a single universe; therefore, the work must be distributed across multiple universes. The branches of the wavefunction are not formal artifacts but real computational substrates.

The argument trades on an intuitive identification of computation with discrete, classical-style step-counting, applied to the multiplicity of components in a quantum superposition. It is rhetorically powerful precisely because it converts an abstract interpretive question—what is the ontological status of the wavefunction's components?—into a concrete resource-counting question.

However, the argument's force depends on at least three assumptions that warrant scrutiny. First, it assumes that the classical step-count provides the correct measure of computational work performed during the quantum algorithm. Second, it assumes that this work must be distributed across discrete, persistent, ontologically robust substrates. Third, it assumes that interference and superposition during unitary evolution constitute parallel computation in a sense that requires each component to be a fully realized world.

Aaronson [22,23] has noted that the Deutsch argument is best understood as an intuition pump rather than a formal proof, and that its appeal depends substantially on framing. In particular, the choice to count classical steps as the measure of computational work begs the question against interpretations that locate the computational resource elsewhere—for example, in the geometry of Hilbert space, in entanglement structure [24], or in the formal multiplicity of amplitudes without ontological branch realism. Cuffaro [6,7] has argued at length that the Deutsch computational explanation is properly classified as a how-possibly explanation, in Hempel's sense, and that competing how-possibly explanations grounded in entanglement structure or in the Gottesman-Knill theorem [8] are equally available.

The most sophisticated defense of the Deutsch-style picture is due to Wallace [25,26], who argues that decoherence-based emergent branch structure provides exactly the substrate the computational argument requires, with branches individuated by functionalist criteria on the relevant timescale. Hewitt-Horsman [27] generalizes this argument to quantum computation explicitly, claiming that branches are stable substructures relevant for the timescales of the computation, not merely the timescales of decoherence, and that by the same functionalist standard used to grant ontic status to ordinary macroscopic objects, coherent computational branches qualify as worlds. We engage Wallace's and Hewitt-Horsman's accounts directly in Section 5.

For present purposes, the key observation is this: the Deutsch argument is not a deduction from the formalism of quantum mechanics to MWI. It is an argument from an interpretation of computational resource use to a corresponding ontology. Whether that interpretation is correct is a substantive question, and one that other interpretations may answer differently while preserving all observable predictions.

3. Interpretive Alternatives and Empirical Equivalence

Quantum mechanics admits a well-known plurality of interpretations, each of which reproduces the empirical predictions of the formalism while making different ontological commitments [28,29]. The principal contenders include Copenhagen-style operational interpretations, the De Broglie-Bohm pilot-wave theory [30], the Everett or Many-Worlds Interpretation [31,32], the consistent or decoherent histories framework [33–35], relational quantum mechanics [36], QBism [37], and various objective collapse theories such as GRW [38] and CSL [39]. Each is generally constructed to reproduce the standard empirical predictions of quantum computation within currently accessible regimes, though some collapse models may imply deviations under sufficiently large or delicate coherence conditions; in what follows we set such regime-dependent deviations aside and treat the interpretations as empirically indistinguishable for present purposes. Table 1 summarizes the principal ontological commitments of these interpretations alongside the records-based pruned-histories view developed in this paper.

Table 1. Ontological commitments across major interpretations of quantum mechanics.

Interpretation	ψ -ontic	Branch realism	Records criterion	Computational ontology
MWI (Wallace, Deutsch)	Yes	Yes (all)	No	Parallel branches as substrates
Pruned histories (this paper)	Yes	No	Yes	Hilbert-space + entanglement structure
Consistent histories	Yes	No	Implicit (decoherence-based)	Probability over decoherent histories
Relational QM	Relational	No	Observer-relative	Relational fact between system & observer
Bohmian mechanics	Yes (nomological in some readings)	No	N/A (definite configuration)	Single guided particle configuration

This empirical equivalence has direct bearing on the Deutsch argument. If multiple interpretations reproduce the predictions of Shor's algorithm without committing to ontologically real parallel branches, then the inference from computational success to branch realism cannot be a deduction from observation alone. It must rest on additional premises that the alternative interpretations reject.

Consider the consistent histories framework, which is particularly relevant for our purposes. Consistent histories treats quantum mechanics as a probabilistic theory over sets of mutually decoherent histories, where only certain consistent sets correspond to physically meaningful descriptions [33,34]. On this view, the formal multiplicity of branches in a quantum computation does not entail the simultaneous physical reality of all branches; it entails only that the formalism supports a probability distribution over alternative histories. The framework has received recent computational implementation in the work of Arrasmith et al. [40], who develop a variational consistent-histories algorithm that runs on quantum processors, supplying empirical legs for the formal claim that history-pruning operations have computational content. The computational speedup is preserved because the unitary evolution that produces interference is part of the formalism; what the consistent histories view denies is that each history corresponds to a separately existing world performing classical-style computation.

Bohmian mechanics offers a different but equally instructive case. On the pilot-wave view, there is a single configuration of particles guided by a universal wavefunction. Quantum computation is a real physical process in which the wavefunction does ontological work, but the parallel-universes language is rejected as a misreading of the formalism [30]. Bohmians can fully account for the empirical success of quantum algorithms without postulating multiple worlds.

Relational quantum mechanics and QBism go further, denying that the wavefunction has observer-independent ontological status at all [36,37]. On these views, the question of "where the computation happens" is a category mistake: the computation is a relational fact between system and observer, not a process distributed across an ontological multiverse. The recent open-systems perspective developed by Cuffaro and Hartmann [41] generalizes this stance, arguing that the assumption of a fundamental universal wavefunction—a load-bearing premise of the MWI-from-QC inference—is itself optional rather than forced by the physics.

The point of this brief survey is not to defend any particular alternative but to establish a structural feature of the interpretive landscape: empirical quantum computing does not, on its own,

discriminate between interpretations. The Deutsch argument, if it is to do its intended work, must therefore rest on grounds beyond bare empirical adequacy. Those grounds are typically intuitions about computational resource use, which we examine and challenge in Section 5.

It bears emphasizing that this empirical equivalence is not a defect or limitation of the alternatives. It is a structural feature of quantum mechanics as currently formulated: the theory's empirical content underdetermines its ontological interpretation. This is sometimes presented as a scandal in need of resolution, but it can equally be read as a methodological constraint on what empirical results can establish.

4. Final-State Constraints and Pruned Histories

The pruned-histories framework, developed in prior work on final-state constraints and informational pruning [14], holds that not all formally allowed histories of a quantum system are ontologically realized. Boundary conditions—particularly final-state conditions of the kind discussed in two-state-vector formulations [15,16,42] and in cosmological and black-hole contexts [17–19]—select against certain histories, restricting the space of ontologically robust branches without modifying the unitary dynamics that govern evolution between boundary conditions.

To fix notation: a closed quantum system evolves under the standard Schrödinger dynamics,

$$|\psi(t)\rangle = U(t) |\psi(0)\rangle \quad (1)$$

where $U(t)$ is the unitary evolution operator of equation (1). In a computational basis $\{|i\rangle\}$, the state admits the expansion

$$|\psi\rangle = \sum_i c_i |i\rangle, \quad \sum_i |c_i|^2 = 1 \quad (2)$$

and measurement outcomes are governed by the Born rule,

$$P(i) = |\langle i | \psi \rangle|^2 = |c_i|^2 \quad (3)$$

Equations (1)–(3) provide the formal scaffolding for the pruning analysis that follows. The framework's physical legitimacy has been substantially strengthened by recent work. Anastopoulos [17] derives the observed cosmic acceleration as a quantum postselection effect arising from final-state boundary conditions, providing a concrete physical context outside black-hole physics in which final-state constraints function as genuine dynamical inputs rather than interpretive overlays. Lloyd and Preskill [19] show that final-state projection models of black-hole evaporation can preserve unitarity to an excellent approximation under generic boundary conditions, with deviations exponentially small in the black-hole entropy, while noting that exact unitarity requires carefully tuned dynamics and that residual causality concerns about measurements inside old black holes are mitigated by computational complexity. Their analysis substantially strengthens, without fully resolving, the case for the Horowitz-Maldacena proposal [18]. Aharonov, Cohen, and Shushi [42] supply the technical scaffolding for treating two-state-vector dynamics in the correspondence limit. Together these results situate the pruned-histories framework within an active and physically motivated research program rather than treating it as a free-floating philosophical proposal.

The framework is best understood as occupying conceptual space between standard Everettian MWI and single-world collapse interpretations. Like MWI, it accepts unitary quantum mechanics without invoking dynamical collapse. Unlike MWI, it denies that all formally allowed branches enjoy equal ontological status; instead, boundary conditions or decoherence-based selection criteria prune the space of realized histories. Formally, pruning is described by a projector \mathcal{F}_p acting on the global Hilbert space \mathcal{H} , mapping the full state to a restricted state on a subspace \mathcal{H}_p indexed by histories satisfying the imposed constraints,

$$\mathcal{F}_p : \mathcal{H} \rightarrow \mathcal{H}_p, \quad \mathcal{F}_p |\psi\rangle = \sum_{i \in S} c_i |i\rangle \quad (6)$$

where $S \subseteq \{1, \dots, \dim(\mathcal{H})\}$ is the index set of histories surviving the constraint. The operator \mathcal{F}_p is introduced here as a schematic representation of constraint-relative ontological selection, not as a proposed modification of Schrödinger dynamics. The result is an ontology that retains the formal apparatus of quantum mechanics while resisting the proliferation of worlds that gives MWI its distinctive metaphysical signature.

Several technical features of the framework are worth highlighting. First, pruning is compatible with full unitary evolution between boundary conditions. The framework does not require modifying the Schrödinger equation or introducing nonlinear collapse mechanisms. Second, pruning operates on histories rather than on instantaneous states, in the sense developed in the consistent histories tradition [33–35]. A pruned history is one whose final state is incompatible with the imposed boundary condition; such histories appear in the formal expansion of the wavefunction but do not correspond to ontologically realized branches. Third, the framework is compatible with multiple physical sources of pruning: cosmological final-state conditions [17], decoherence-induced selection of pointer bases [43], or relational constraints between subsystems and observers. Figure 1 illustrates this structure.



Figure 1. The Architecture of Constraint-Relative Pruning. Formal expansion of the wavefunction in the global Hilbert space \mathcal{H} generates the full set of formally allowed computational histories. Constraint-relative pruning—via boundary conditions, decoherence-based selection, or relational observer-system constraints—restricts this to a history space \mathcal{H}_p whose realized members are those compatible with environmental records. Unitary evolution preserves amplitude structure on the left branch; unrealized histories remain formal but are not ontologically populated, eliminating the need for a computational multiverse.

For the present discussion, the key feature of the pruned-histories framework is its treatment of branch multiplicity. On the framework, the wavefunction’s formal multiplicity during unitary evolution—its decomposition into amplitudes corresponding to different computational paths—is fully retained. What is denied is that this formal multiplicity, after measurement or boundary-condition imposition, corresponds to a population of equally real persistent worlds, each of which constitutes an ongoing computational substrate.

This distinction is crucial for the argument that follows. Quantum computational speedup depends on the formal multiplicity of amplitudes during unitary evolution and on the interference

patterns this multiplicity supports. It does not depend on the post-measurement persistence of all branches as ontologically robust parallel worlds. The pruned-histories framework grants the former while denying the latter, and we argue in the next section that this is precisely the conceptual move needed to defeat the Deutsch inference—provided we supplement it with a records-based criterion for ontological commitment and a positive account of what underwrites computational speedup.

5. Can Pruned Histories Support Quantum Speedup?

The Deutsch argument, stripped to its core, runs as follows. Shor's algorithm factors integers exponentially faster than any known classical algorithm. For sufficiently large input, the number of elementary computational steps required classically exceeds any plausible resource budget of the observable universe. Yet the quantum algorithm produces the answer. Therefore the computation must occur somewhere, and since it does not occur in this universe's classical resources, it must occur in others. The branches of the wavefunction are not merely formal artifacts; they are the computational substrate.

This argument has rhetorical force, but it conflates claims that must be separated. Figure 2 visualizes the dialectic: the Deutsch chain on top, our pruned-histories reply on the bottom. The first claim Deutsch's argument runs together is that quantum computation exploits a computational resource not available to classical computation. This is uncontroversial and empirically well-grounded. The second claim is that this resource consists in the persistent ontological reality of all formally allowed branches, each of which is itself performing classical-style computation. The second claim is what does the metaphysical work in Deutsch's argument, and it is this claim we challenge. The challenge requires three positive commitments, summarized in Table 2: a records-based criterion for ontological commitment, a thermodynamically graded boundary between unitary computation and outcome-stabilization, and a positive account of speedup grounded in global Hilbert-space and entanglement structure.

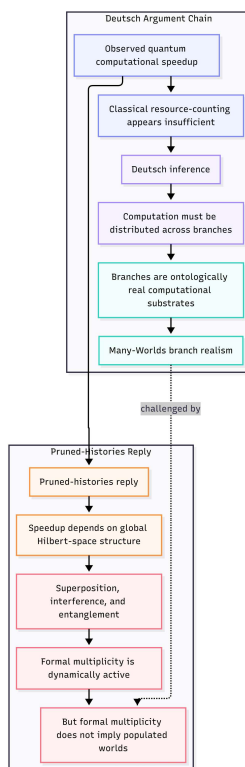


Figure 2. Deutsch's Argument and the Pruned-Histories Reply. The Deutsch argument chain (top) moves from observed quantum speedup to Many-Worlds branch realism via the premise that classical resource-counting is

insufficient. The pruned-histories reply (bottom) grants superposition, interference, and entanglement as dynamically active features of the formalism while denying that formal multiplicity entails a population of ontologically realized worlds.

Table 2. The three positive commitments of the records-based pruned-histories framework.

Commitment	Function	Objection it pre-empts
Records-based criterion (eq. 5)	Restricts ontic commitment to outcomes with redundantly accessible environmental records	Hewitt-Horsman functionalist parity: distinguishes branches from tigers in a principled way
Thermodynamically graded boundary (eq. 4)	Replaces sharp computation/measurement binary with a continuous spectrum indexed by environmental coupling	Demarcation problem: avoids inheriting the measurement problem or collapsing into Wallace's decoherence-realism
Hilbert-space + entanglement account of speedup (eqs. 7, 8)	Locates the computational resource in global state structure ($\dim 2^n, S(Q_a) > 0$), not in branch population	Cuffaro positive-replacement demand: answers what underwrites the speedup if not parallel computation

5.1. The Computational and Outcome-Stabilization Phases

Any quantum algorithm can be decomposed into a unitary evolution followed by measurement [44]. During unitary evolution, the system explores a high-dimensional Hilbert space; amplitudes for different computational paths interfere constructively or destructively; the algorithm's design ensures that amplitudes corresponding to correct answers reinforce while incorrect answers cancel. At measurement, a single outcome is registered, with probabilities given by the Born rule given in equation (3).

The Deutsch argument treats this entire process as parallel computation across branches. We propose, instead, that the relevant boundary is not between two physically distinct regimes but between two ends of a thermodynamic spectrum: between unitary processing isolated from environmental coupling on one end, and outcome-stabilization through environmental record-formation on the other. The boundary is graded rather than sharp. The transition is captured by the partial trace over environmental degrees of freedom,

$$\rho_s(t) = \text{Tr}_e [|\Psi(t)\rangle\langle\Psi(t)|] \rightarrow \sum_i |c_i|^2 |i\rangle\langle i| \quad (4)$$

in which the system's reduced density matrix $\rho_s(t)$ approaches a diagonal form in the einselected pointer basis as environmental entanglement grows. What individuates the regimes is the presence or absence of redundant environmental records in the Zurek-einselection sense [43], which is a thermodynamic condition on environmental coupling and irreversibility.

We adopt, accordingly, a records-based criterion for ontological commitment. Formally, an outcome i is ontologically committing—written $\mathcal{R}(i)$ —only if there exists an environmental subsystem E in the broader environment \mathcal{E} whose reduced state conditioned on outcome i is orthogonal to its reduced state conditioned on every alternative outcome $j \neq i$:

$$\mathcal{R}(i) := \exists E \subseteq \mathcal{E} \text{ such that } \rho_{e|i} \perp \rho_{e|j} \text{ for all } j \neq i \quad (5)$$

Equation (5) formalizes the criterion of redundant accessible records. It is a substantive metaphysical commitment, not a deflation. It aligns the framework with the consistent-histories

tradition [33–35] and with the realist construals of decoherence theory [43,45]. It is also more austere than Wallace's emergent realism, which extends ontic commitment to all decoherence-stabilized branches; the records-based criterion further requires the records to be redundantly accessible, which on the present view is what distinguishes outcomes from merely coherent computational pathways.

The redundancy requirement is important. Mere formal decomposability or temporary computational stability is not sufficient for ontological commitment, because both can occur within isolated unitary dynamics without producing observer-independent records. Redundant environmental accessibility marks the transition from internally functional structure to externally stabilized fact. This is the point at which the framework treats an outcome as ontologically committing, and it is what distinguishes the records-based criterion from the more permissive decoherence-based realism of standard Everettian accounts. Figure 3 presents the criterion as a decision flow: outcomes that satisfy $\mathcal{R}(i)$ become ontologically committing classical records, while those that do not remain formal computational pathways without populated branch ontology.

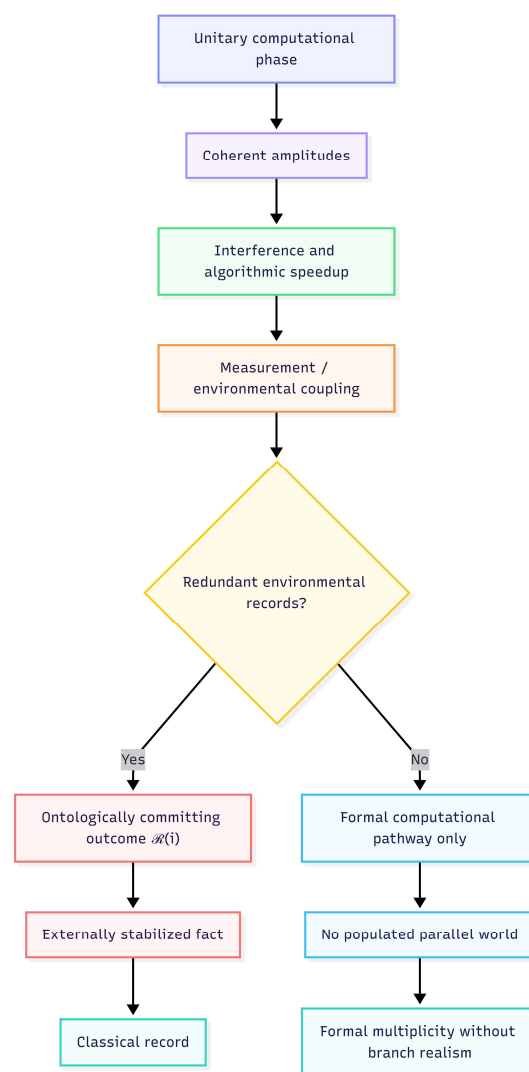


Figure 3. The Records-Based Criterion as a Decision Flow. A unitary computational phase generates coherent amplitudes that interfere to produce algorithmic speedup. At measurement, environmental coupling raises the question of whether redundant environmental records have formed. If yes, the outcome is ontologically committing in the sense of $\mathcal{R}(i)$ and becomes an externally stabilized classical record. If no, the structure remains a formal computational pathway — formal multiplicity without branch realism, and no populated parallel world.

On this view, the question for ontology is not where the computation happens but what gets stabilized as an outcome. The unitary phase generates a structured wavefunction whose amplitudes encode the algorithm's answer; the outcome-stabilization phase converts that structure into records. The exponential speedup is a property of the unitary phase. The ontological commitments are incurred at the records phase. There is no need to populate the unitary phase with parallel worlds.

5.2. Where Pruning Operates

The pruned-histories framework, formalized via the projector \mathcal{F}_p introduced in equation (6), holds that not all formally allowed histories are ontologically realized; final-state constraints, or in weaker formulations decoherence-based selection, prune the space of histories down to those consistent with observed boundary conditions [14]. Pruning should be understood as an ontological constraint on the status of histories, rather than as a modification of unitary dynamics. During computation, the full amplitude structure remains dynamically active; pruning concerns which histories are later treated as ontologically realized under boundary-condition and records-based criteria. The wavefunction during the computational phase still contains all the amplitudes c_i in equation (2); the interference still occurs; the algorithm still runs. What pruning denies is that each formally distinguishable component of the unitary wavefunction corresponds to a separately realized world.

This is sufficient to block the Deutsch inference without disturbing the empirical predictions. Quantum computing works because superposition and interference are real features of the unitary dynamics. Pruning, supplemented by the records-based criterion of equation (5), denies that the formal multiplicity of the wavefunction during computation entails a corresponding ontological multiplicity of worlds.

To put it sharply: Deutsch's argument requires that branches be ontologically real, that they persist, and that they each constitute a site of classical-style computation. The pruning view grants the formal multiplicity required for interference, denies the persistence and the parallel-computation reading, and is therefore not committed to the computational multiverse. The speedup is preserved; the multiverse inference is not.

5.3. The Interference Objection and the Limits of Wave Analogies

The natural objection is this: if pruning denies the reality of branches, how can interference between them produce the speedup? Does interference not require that the interfering paths be real?

It is tempting to deflate this objection by analogy to classical wave Fourier decomposition: the components of a Fourier expansion are not separate physical waves but formal decompositions of a single field. We acknowledge that this analogy is suggestive and provides intuitive support for the formal-multiplicity reading, but we do not rest the argument on it. The disanalogies are real and were pressed against Steane and Cuffaro by Hewitt-Horsman [27] and implicitly by Wallace [25]. Quantum branches in an n -qubit register live in a Hilbert space whose dimension scales exponentially with n , as given in equation (7),

$$\dim(\mathcal{H}_{\{n\}}) = 2^n \quad (7)$$

and subsystem operators act locally on tensor factors; classical Fourier components do not exhibit this exponential dimension scaling and are not subject to local operations on tensor factors. Counterfactual computation results [46,47] further suggest that branches leave dynamical traces in ways Fourier components do not. The wave analogy captures something correct about formal-versus-ontological multiplicity, but it cannot bear the full weight of the argument.

The argumentative weight is borne, instead, by the records-based criterion of §5.1 and by the positive account of speedup in §5.4. Interference during the unitary phase requires that the amplitudes c_i be formally present and dynamically active. It does not require that each interfering component correspond to an ontologically robust parallel world. What it requires, on the records-

based view, is that the wavefunction itself be ontologically robust—which we grant—and that local unitary operations act on its tensor structure—which we also grant. What we deny is that this structure entails a population of worlds at the level of components.

5.4. What Underwrites the Speedup

A coherent denial of the Deutsch inference must answer the positive question Cuffaro [6,7] presses against deflationary readings: if not parallel branches, then what underwrites Shor's exponential speedup? We answer: the dimension scaling of equation (7), together with non-trivial entanglement structure, captured for a bipartite cut into subsystems a and b by the von Neumann entropy of the reduced density matrix ρ_a ,

$$S(\rho_a) = -\text{Tr}(\rho_a \log \rho_a) > 0 \Leftrightarrow \text{entanglement} \quad (8)$$

and together with the local-operation structure that allows tensor-factor unitaries to manipulate that global structure efficiently.

The technical content of this answer is given by results in the philosophy and theory of quantum computation. Jozsa and Linden [24] establish that the presence of multipartite entanglement, with a number of parties scaling unboundedly with input size, is necessary for any pure-state quantum algorithm to deliver exponential speedup over classical computation. Jozsa and Linden themselves caution against viewing entanglement as the sole key resource for quantum-computational power, and we adopt the same caution: their result identifies a necessary structural feature of the wavefunction supporting speedup, not a complete metaphysical account of the computational resource. The Gottesman-Knill theorem establishes that quantum circuits restricted to stabilizer operations are efficiently classically simulable, even though such circuits can generate entangled states. Cuffaro [8] argues against the natural inference that entanglement is therefore insufficient for quantum advantage; on his reading, the theorem shows rather that stabilizer-restricted circuits fail to exploit the full computational potential of the entangled states they generate. We adopt Cuffaro's reading: stabilizer-classical simulability marks the boundary at which quantum-mechanical resources begin to do distinctively non-classical work, and that boundary is informative about the structural features of speedup without reducing those features to a single named resource. Together, these results suggest that the locus of speedup is best identified with structural features of the global wavefunction—dimension, multipartite entanglement, and local-operation accessibility—rather than with the ontological multiplicity of branches. The exact characterization of the relevant structural features remains an active topic in the philosophy of quantum computation.

On this account, the explanatory work in Deutsch's argument is done not by the parallel computation of branches but by the dimensionality and entanglement structure of Hilbert space. Duwell [5] makes a related point: MWI's apparent explanatory advantage in quantum computation derives from the ontological status MWI accords to the universal state vector, not from the particular ontology of branches. Any state-vector realist can borrow that explanatory apparatus without ontic branch commitment. The pruned-histories framework, supplemented by the records-based criterion of equation (5), is precisely such a state-vector realism without branch realism.

5.5. The Hewitt-Horsman Functionalist Challenge

The deepest counter to the present argument is due to Hewitt-Horsman [27], who defends branch realism for quantum computation on functionalist grounds. By the same functionalist standard used to grant ontic status to ordinary macroscopic objects—cells, chairs, tigers—coherent computational branches qualify as worlds, because they are stable substructures relevant for the timescales of the computation. The challenge is one of parity: an austere ontology that strips out branches as merely formal risks, by parity, also stripping out emergent macroscopic ontology.

We accept the parity demand and meet it with the records-based criterion. The principled cut between branches and tigers is encoded in equation (5): tigers leave redundantly accessible

environmental records that satisfy $\mathcal{R}(i)$; coherent computational branches, prior to environmental coupling, do not. Records-based realism is not gerrymandered to fit the desired conclusion; it tracks an independently motivated criterion in the literature on quantum-to-classical transition [43,45]. Tigers, cells, and chairs are stabilized by overwhelming environmental coupling on their characteristic timescales; coherent computational branches in a well-isolated quantum register are stabilized only on the algorithmic timescale and only relative to the system's internal structure, with no redundant external records.

Hewitt-Horsman's functionalist criterion identifies branches as stable substructures relevant for the computation. We grant the formal description but deny that it suffices for ontic commitment. Functional relevance for an internal computation is weaker than redundant external record-formation, and the records-based criterion treats only the latter as ontologically committing. The cost of the records-based criterion is that it is more austere than Wallace's emergent realism; the benefit is that it discriminates by principle the cases the Deutsch argument needs to merge.

5.6. A Diagnostic Observation

The cleanest way to see what is at stake is to ask: what would change empirically if pruning were correct and Deutsch were wrong? Nothing. Both views predict the same Born-rule probabilities given by equation (3), the same speedups, the same decoherence patterns described by equation (4). This is not a defect of the argument; it is the situation we should expect when the dispute is genuinely interpretational. But it does mean that the Deutsch argument cannot be marshaled as empirical support for MWI without smuggling in the ontological commitments it purports to establish.

The argument is not "quantum computing works, therefore MWI." It is "if MWI is true, here is a satisfying explanation of why quantum computing works." That is a weaker and more honest claim, and it is compatible with pruned-histories alternatives offering their own satisfying explanations. The records-based pruned-histories view offers exactly such an explanation: the speedup is grounded in Hilbert-space dimension and entanglement structure as in equations (7) and (8); the ontological commitments are incurred only at outcome-stabilization via equation (5); and Deutsch's parallel worlds are formally indispensable to the computation but not ontologically populated.

6. The Ontological Models Framework

To sharpen the analysis, we situate the dispute within the ontological models framework developed by Spekkens [48] and refined by Harrigan and Spekkens [49]. The framework provides a rigorous vocabulary for discussing what an interpretation of quantum mechanics commits to ontologically, and it allows the question "what does quantum speedup require?" to be posed precisely.

On the Spekkens-Harrigan distinction, an ontological model is psi-ontic if the quantum state is a feature of objective reality—distinct quantum states correspond to distinct ontic states—and psi-epistemic if the quantum state represents knowledge or information about an underlying reality whose distinct states may be compatible with multiple quantum descriptions. The PBR theorem [50] places strong constraints on psi-epistemic models, though significant interpretive flexibility remains.

The Deutsch computational argument, formalized within this framework, makes two distinct ontological claims. The first is a psi-ontic claim: the wavefunction corresponds to objective ontological structure. The second, more demanding claim is what we may term branch realism. By branch realism we mean the stronger thesis that formally distinguishable components of the wavefunction correspond to ontologically realized, computationally active worlds—each persisting after measurement and each constituting a site of classical-style computation during the unitary phase.

The pruned-histories view accepts the first claim but rejects the second in the demanding form Deutsch's argument requires. On the pruning view, the wavefunction is psi-ontic in the sense that its global structure is a feature of reality, but the ontology does not include a population of fully realized parallel worlds corresponding to each formal branch. Records-based commitment further restricts

ontic status to outcomes stabilized by environmental coupling per equation (5), leaving the unitary phase with formal but not populated multiplicity.

This refinement allows us to articulate the dispute precisely. The disagreement between Deutsch-style branch realism and the records-based pruning view is not about whether the wavefunction is ontologically robust; both agree that it is. The disagreement is about whether the wavefunction's formal multiplicity, at all stages of evolution and persistence, corresponds to an equivalent ontological multiplicity. Deutsch says yes; the pruning view says no, and supplies the records-based criterion as the principled cut.

Within the ontological models framework, this is a substantive but conceptually clean disagreement. Both views are psi-ontic in the broad Spekkens-Harrigan sense. Both reproduce the Born rule. Both accommodate observed quantum computational speedup. They differ on the ontological status of unrealized branches, and that difference is invisible to empirical test of the kind that the Deutsch argument purports to deploy.

An immediate consequence is that the minimal psi-ontic ontology required for quantum computational speedup is significantly less than the demanding branch realism Deutsch's argument needs. The minimal ontology requires that the wavefunction's structure be objective, that unitary evolution faithfully implement that structure, and that records be ontologically committing. It does not require that every formally distinguishable component correspond to an ontologically realized parallel world. The Deutsch argument moves from the minimal requirement to the demanding one without justification beyond intuitions about computational resource use, and those intuitions, as we have argued, are interpretive rather than empirical.

7. Observer-Dependence Theorems and the Interpretive Landscape

Recent foundational results have constrained the space of viable interpretations in ways that bear on the Deutsch argument. The most relevant are the Frauchiger-Renner thought experiment [9], the no-go theorem of Bong et al. for observer-independent facts [10], and recent contextuality-based extensions [11–13].

The Frauchiger-Renner argument purports to show that no single-world interpretation that respects unitary quantum mechanics, includes observers as quantum systems, and treats agents as making consistent predictions can be self-consistent. The argument has been read as supporting MWI by elimination, on the grounds that MWI denies the single-world premise and is therefore exempt from the contradiction. However, the argument has been extensively debated [51–53], and the conclusion that it specifically vindicates MWI is contested. Bub [51] develops a single-world reading that models agents as quantum computers and rejects the inference to MWI; Lazarovici and Hubert [52] argue that the contradiction dissolves on certain Bohmian readings.

The most directly relevant recent contribution is Steane [20], who develops a multi-pronged analysis of the extended Wigner's friend scenario. Steane argues that extended Wigner's friend results rule out interpretations involving subjective collapse but do not by themselves discriminate single-world from many-world frameworks; he further argues that single-world interpretations remain viable when certain outcomes are not subject to quantum erasure, with the notion of permanent records doing critical work in his account. Steane's analysis is congenial to the records-based pruned-histories view developed here, particularly in its emphasis on permanent records, though Steane himself leans toward single-world realism while the present paper occupies a more cautious position between standard single-world realism and full Everettian branch realism.

The Bong et al. theorem [10] strengthens the case against observer-independent facts by deriving an inequality, analogous to a Bell inequality, whose experimental violation would rule out a class of interpretations committed to a single observer-independent reality of measurement outcomes. Experimental tests have reported violations consistent with the theorem's predictions [54], though the implications remain debated. Wiseman, Cavalcanti, and Rieffel [13] refine the theorem with what they term a "thoughtful" version requiring weaker assumptions; Wallegghem et al. [11,12] derive related results from contextuality rather than nonlocality, removing the post-selection step in

Frauchiger-Renner. Adlam [55] offers a deflationary analysis of what "non-absoluteness of observed events" means in this literature, gesturing toward retrocausality of a special kind—a connection that dovetails with the final-state-constraint dimension of pruned histories.

These results put pressure on certain forms of single-world realism, particularly those that combine observer-independence with consistent application of quantum mechanics to observers as physical systems. They do not, however, specifically vindicate the demanding branch realism that the Deutsch computational argument requires. The pruned-histories view occupies a position that is neither standard single-world realism nor full Everettian branch realism, and the observer-dependence results constrain it in a different way than they constrain either pole.

Specifically, the pruning view can accommodate observer-dependence by allowing that boundary-condition specifications are themselves observer-relative or relational, in a way consistent with relational quantum mechanics [36] or with the framework developed by Healey [56,57]. On such a view, what is pruned and what is realized depends on the relevant observer-system relation, and there is no observer-independent fact about which branches are real. This dovetails with the observer-dependence theorems without committing to MWI's persistent population of worlds.

The upshot is that the post-Frauchiger-Renner interpretive landscape is more fragmented than the simple choice between MWI and Copenhagen suggests. Pruned-histories views, relational interpretations, consistent-histories accounts, and open-systems perspectives [41] all occupy interesting middle positions, and the Deutsch argument must contend with this fuller landscape rather than treating MWI and naive collapse as the only options.

8. What Quantum Computing Actually Demonstrates

It will be useful to offer a positive account of what empirical quantum computing demonstrates about quantum ontology, distinct from what it does not demonstrate. The account is deliberately cautious, in keeping with the methodological constraint that empirical results underdetermine ontological interpretations.

Empirical quantum computing demonstrates, first, that Hilbert space structure is physically robust. The dimensionality of quantum systems given by equation (7) is real in a sense that resources scale with: doubling the number of qubits genuinely doubles the dimensionality of the computational space, and observed speedups depend on this scaling. This is a substantive result with ontological implications, but the implications are weaker than branch realism. They establish that the formal apparatus of quantum mechanics tracks physical reality, not that each formal component of a superposition corresponds to a separately existing world.

Empirical quantum computing demonstrates, second, that superposition and entanglement—formalized via equations (2) and (8) respectively—are computational resources [8,24]. They enable computational tasks that are not achievable by classical means within plausible resource budgets. This is a deep fact about the physical world—classical resources do not suffice to simulate quantum systems efficiently—and it warrants substantial revision of pre-quantum intuitions about what computation is. But the fact that quantum resources outperform classical ones does not, by itself, settle the question of how those quantum resources are best described ontologically.

Empirical quantum computing demonstrates, third, that decoherence is a real dynamical process that produces effective branch structure during interaction with environments [43,45]. This is consistent with multiple interpretations and does not, by itself, vindicate any of them. Decoherence explains why we observe definite outcomes; it does not explain whether unobserved branches persist as ontologically real worlds.

What empirical quantum computing does not demonstrate is the ontological reality of a computational multiverse. The Deutsch argument moves from the empirical facts above to the multiverse conclusion by way of additional premises about computational resource use, and those premises are interpretive. They may be defensible on independent grounds—Wallace [25,26] offers the most thorough defense and Hewitt-Horsman [27] the most sustained application to quantum computation—but they are not established by the empirical success of quantum computing.

This positive account aligns with the cautious methodological stance that has characterized the most careful work in quantum foundations. The success of quantum mechanics as a predictive theory is overwhelming; the question of its ontological interpretation remains genuinely open; and empirical results, including those from quantum computing, constrain rather than settle the interpretive question.

9. Conclusion

Deutsch's computational argument has served as a powerful intuition pump for branch-realist interpretations of quantum mechanics. It is not, however, a deduction from empirical fact to MWI. The argument depends on interpretive premises about computational resource use that other interpretations reject, and the existence of coherent alternatives—pruned-histories views among them—defeats the argument's pretension to interpretation-neutrality.

We have argued that the pruned-histories framework, supplemented by a records-based criterion for ontological commitment formalized in equation (5) and a positive account of speedup grounded in Hilbert-space dimension and entanglement structure as captured in equations (7) and (8), can underwrite quantum computational speedup without committing to a computational multiverse. Pruning, formalized schematically via the projector \mathcal{F}_p in equation (6), constrains the ontological status of histories without modifying unitary evolution; records-based commitment confines ontic status to outcomes stabilized by environmental coupling; and the explanatory work for speedup is borne by global Hilbert-space structure, with results from Jozsa-Linden [24] and Cuffaro's analysis of the Gottesman-Knill theorem [8] supplying the technical content. The framework grants the formal multiplicity required for interference, denies the demanding branch realism Deutsch's argument requires, and accommodates the empirical predictions of quantum computation in full.

The framework meets Hewitt-Horsman's [27] functionalist parity challenge by drawing a principled cut at redundant external records rather than at internal computational stability, in line with established work on the quantum-to-classical transition [43,45]. It accommodates recent observer-dependence theorems [9–13] in the manner urged by Steane [20], who argues that extended Wigner's friend results do not discriminate single-world from many-world frameworks. And it inherits the explanatory apparatus available to any state-vector realist, in the manner suggested by Duwell [5].

Three implications follow. First, popular and semi-technical presentations of quantum computing should be more cautious about the claim that quantum advantage "proves" MWI. The claim is interpretive, not empirical, and presenting it otherwise misleads readers about the structure of the argument. Second, foundational research should take seriously the space of interpretations between standard MWI and naive single-world collapse, including pruned-histories accounts, relational interpretations, consistent-histories frameworks, and open-systems perspectives [41]. Third, the question of what minimal ontology is required to underwrite quantum computational speedup is itself a productive research question, and one that deserves attention separate from broader debates about quantum interpretation.

Several questions remain open. The full technical articulation of pruned-histories ontologies, particularly in cosmological and field-theoretic contexts following Anastopoulos [17], requires further development. The compatibility of pruning with specific quantum algorithms beyond Shor's—for example, with quantum simulation algorithms or quantum machine learning protocols—deserves systematic examination. The connection between pruned-histories views and the observer-dependence theorems, sketched in Section 7, warrants more rigorous treatment. And the relationship between records-based realism and the open-systems perspective developed by Cuffaro and Hartmann [41] is a natural site for further work. We hope to address these questions in subsequent work.

Empirical quantum computing is one of the great achievements of contemporary physics. What it shows about quantum ontology is significant but bounded. It shows that quantum mechanics is

right about the physical world; it does not show that any particular interpretation is right about quantum mechanics. The Deutsch argument, for all its rhetorical force, does not bridge that gap. Quantum computation shows that the structure of the wavefunction matters physically; it does not, by itself, show that every branch of that structure is a world.

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